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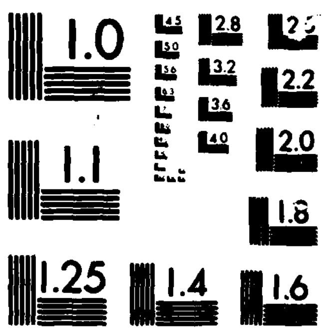

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This report summerizes our progress and results during this reporting period. Our experiments show that the growth of thick (≥5 μm) superlattice samples of HgTe/CdTe requires the use of an MBE system with in-situ diagnostic capability to assure stability of growth parameters for periods of several hours. Our efforts with our in-house MBE system have not succeeded in growing thick superlattice samples needed for the optical experiments.

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PROGRAM PROGRESS

During this reporting period several HgTe/CdTe superlattice samples were grown with thicknesses ranging from 2 to 4 μm. However, RHEED measurements on these samples showed polycrystallinity and the absence of supperlattice structure. We believe this is due to the intrinsic drift in our system. The lack of in-situ RHEED measurement capability in an MBE machine does not allow us to control the growth parameters and compensate for the drifts in our system during the many hours needed for the growth of thick supperlattice samples. We have been able to grow thin supperlattice samples up to .5 μm with good structure with our MBE system taking up to 45 minutes for the growth. This indicates that our existing MBE machine is stable for periods up to 45 minutes. On the other hand, the growth of thick (~5 μm) HgTe/CdTe superlattices takes several hours, and requires the stable operation of MBE system for at least that length of time. This issue as well as our findings so far are discussed in more detail in the nest section.

We have made several attempts to acquire thick HgTe/CdTe samples from outside sources for our optical experiments. Although these attempts are continuing, we have not succeeded so far in securing workable samples primarily due to small number of growers and material researchers in this area and a large demanded for these samples.

SUPPERLATTICE GROWTH PROBLEMS

The fabrication of epitaxial HgTe/CdTe superlattice involve the atomic layer by layer crystal growth of molecular beam epitaxy. This particular superlattice involves the growth of an integer number of HgTe atomic layers grown on top of a different integer number of CdTe atomic layers, and this whole pattern is replicated an integer number of times. The key concept of molecular beam epitaxy is that the growth of a given material replicate the epitaxy of the substrate or the starting atomic surface. The potential problem arises in the superlattice of two different materials (e.g., HgTe and CdTe) in that the previous HgTe layers act as a starting template for the next CdTe layers, which in turn acts as template for the next set of HgTe layers and so forth. In a superlattice materials of say 100 periods, there are 200 surface that initiate epitaxial growth. If for some reason one of these surfaces were to develop defects, steps,

twins, dislocation, antiphase disorder, or any other imperfection, then the layers growing on top of this layer will replicate these atomic defects. Once this happens all the subsequent superlattice layers will begin to replicate these defects and the disorder in this atomic system rapidly increases and the quality of the superlattice rapidly degrades.

Theoretical Monte Carlo calculations on expitaxial superlattice growth have shown that, assuming a perfect MBE machine, the longer a sample is atomically grown or the thicker the superlattice becomes, the probability of statistical atomic fluctuations will cause epitaxial "mistakes" to occur and with sufficient replication the quality of the sharp interfaces and crystalline quality will start to deteriorate. Given this situation, a less than perfect MBE machine will only increase the chances of growing poor quality superlattice samples.

Some of the most important parameters for growing HgCd/Te compounds are the substrate growth temperature and the molecular beam fluxes of the individual tellurium, cadmium, and mercury sources, in particular the mercury source. These parameters must be closely monitored and controlled during the growth process. The substrate growth temperature is monitored by an in-situ thermocouple sensor and ex-situ by a low temperature optical pyrometer, in addition to which during each growth run, eutectic materials are placed on the substrate block to insure proper temperature calibration.

The next most important factor is the control of the mercury beam flux. The mercury beam originates from a quartz reservoir uniformly heated by a close-fitted tube furnace and the temperature is monitored by a theromocouple placed in direct contact with the mercury cell. The mercury beam flux is monitored by an ion gauge in the evaporation chamber. (typically Hg cell temperature are 100°C and Hg pressures of 10^{-4} Torr and substrate temperatures of 180°C for growing (HgCd/Te superlattice). Both the CdTe and Te cells have separate thermocouples and are highly reproducible with respect to beam flux density. If for some reason the substrate temperature on the Hg cell were to drift by 1 or 2°C in real temperature but not in instrument temperature, samples would be of poor quality. [This is in contrast to GaAs technology where a 10°C temperature differential for the substrate temperature is still acceptable.]

Consequently if the time it takes to make a sample is less than the intrinsic MBE machine drift time, then good quality superlattice can be made. The growth rate is fixed at about 1 μm/hr, and can not be increased by much, and since most of our good superlattice films are of 1 μm or less, the drift time for the machine parameters seems to be about 1 hour for the (Hg,Cd) Te alloy system.

One way around this problem of machine drift is to monitor the epitaxial growth layer by layer with an situ Reflector High Energy Electron Diffraction (RHEED) capability. The RHEED monitors in situ atomic growth in real time and by monitoring the RHEED pattern every 1/4 hr, the machine parameters can be more accurately changed to improve epitaxial growth by viewing the situation atomically and not just using microscopic temperatures and pressure sensor devices on the MBE machine. All commercial and custom made machines will have varying degrees of intrinsic drift, and since the (Hg,Cd) Te alloy system is extremely sensitive to machine drift, then an in-situ RHEED capability is rather critical for growing thick samples or equivalently for long periods of time. Our present MBE machine does not have an in situ RHEED, but the RHEED analysis is done in a separate chamber, and the RHEED pattern after all the growth is completed. Our RHEED capability is only used as a past diagnostic tool to determine the quality of previously grown material and can not be used to control the growth of material in real time. If a sample is determined to be of poor quality, there is no way determining when or at what point in the superlattice growth the material started to deteriorate in quality. Without the dynamic real time feedback of an in-situ RHEED capability is the growth chamber, epitaxial growth of superlattice samples for times longer than the intrinsic machine drift time of HgTe/CdTe superlattice is short of impossible unless one is statistically fortunate in the limit of a large number of sample runs.

Financial

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